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## Second generation swimming feedback device using a wearable data processing system based on underwater visible light communication

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### Abstract

Swimmers performance evaluation is important for the swimmers, their coaches and trainers. Most systems depend on visual, video processing or sensors and require post processing to obtain the swim data. Stroke rate, stroke length and swim velocity data are useful parameters for a swimmer during a swim. Swimmers can then adjust their swim to achieve optimal performance. A wearable data processing system was designed, implemented and tested using visible light communication. A wrist-mounted accelerometer with a communications link to a receiver located on the goggles allows visual information to be given to the athlete. This helps swimmers to swim with consistent pace based on a multi-coloured display. The data processing system was based on a circular buffer to read real time acceleration data. The maximum acceleration and the position of the maximum acceleration during one stroke are determined in firmware. The time difference between strokes is transmitted to the goggles. An algorithm at the receiver uses the data to switch on the LED colour so that the swimmer reacts according to previous instructions. The second generation system (size 35 x 35 mm, cost \$19.89AU) was designed and implemented. The system was tested with different swim speeds (slow and fast) and different strokes (free style, back stroke, breast stroke and butterfly) to validate the system. These experiments were used to optimise the system and verify that the complete system is viable under different conditions, styles and swimmers.

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## 1. Introduction

Monitoring swimmers performance is important for swimmers, trainers and coaches. Previously, video camera systems and some bulky or complex equipment were used. With continuing improvements in the size and function of electronics, microprocessors and wireless tiny sensors can be designed for coaches wishing to identify small details in technique. Video information is difficult to interpret due to the large clouds of air bubbles generated by the swimmer's hands and legs. This makes frame-by-frame video processing time consuming.

Inertial sensors including accelerometers and/or gyroscopes are becoming popular to use not just in swimming but also in different sports. This is because these sensors are small, light, easy to use and to setup and waterproof [1]. However, most of these sensors record the data in a memory and then post processing can be applied.

This paper presents a system to provide a real time for swimmers during swimming based on optical wireless communication in the visible spectrum for pacing the swimmer according to the coach instructions. The system includes an accelerometer and transmitter on a swimmer's wrist and a receiver on the swimmer's goggles. The time difference between strokes is sent to the receiver on the goggles to activate a RGB LED and the swimmer is instructed to react according to the light colour [2].

## 2. Swimming feedback literature

Real time feedback can help swimmers to adjust their style and stroke rate to reach the optimum performance [3]. This section presents some of the literature related to various swimming systems.

Some researchers use post processed video for feature extraction. Seifert et al [4] used video data to extract the stroke rate, stroke length and swimmer velocity. No real time feedback is possible.

A wearable system called swimmaster [5] is based on two independent parts, the recording system including the accelerometer, the microcontroller and the memory to record the swim data and feedback to pool side is based on a fixed sequence of commands using an LED blinking sequence. Thus a coach on the pool deck can evaluate the swimmer's response by watching how accurately the commands were followed by the swimmer. This system does not provide real time feedback for a swimmer.

Davey et al [6] designed a low cost sensor to investigate human motion such as walking, monitoring and swimming. The sensor was based on using a 3-axis accelerometer, microcontroller and memory. An on board USB chip and connection to a PC make the communications between the sensors and computer and vice versa easy. Embedded algorithms including filtering were applied to the raw acceleration data. No real time feedback was provided to the trainer.

Rocha et al [7] presents a wearable sensor network for monitoring body kinematics. Three axis accelerometers and magnetometers are connected to a microcontroller and embedded in the swimming suit. The sensors provided heart rate, stroke frequency and temperature. The data is transferred to a base station using a 2.4 GHz transceiver. The sensor network can distinguish between motion and rotation. No real time feedback was presented in this system.

Silva et al [8] presents a wearable monitoring system for swimming performance and movement for health analysis. The system was based on three main units: the sensors including an accelerometer and gyroscope, the processing unit (microcontroller), and a radio for data transmission. The sensor weighs 65.6 grams and measures  $57 \times 90.5 \times 24 \text{ mm}^3$ . The sensor is placed on the upper back of the swimmer to obtain different parameters including style, strokes and end of pool turns. No real time feedback is provided to swimmers in this system.

Sage et al [9] developed a wearable system for processing and transmitting swimming data to an access point. The stroke rate, stroke length and lap count is presented to coaches during training. The proposed system was based on a wireless sensor node, vision components and pressure and force measurement. The data was processed in the node and sent to a computer using RF. The node included a dual-axis gyroscope, a tri-axis accelerometer, and microcontroller unit with integrated radio transceiver. The node was tested in water and the results showed that the link was robust for 35m at 25cm depth. The sensor node could transmit 50Hz data with 10 bit resolution. The topology of the network was a star with a waterproof and attached to the swimmer's back. There is no real time feedback for the swimmer.

Ohgi et al [10-11] developed a wearable sensor to observe the underwater stroke motion and compare it with three dimensional video in two different swimming styles including freestyle and breaststroke. The sensor was based on a tri-axis accelerometer and gyroscope and attached to the swimmer's wrist. Swim stroke phases were observed based on the acceleration and angular velocity data. The results for the stroke phases were matched to the Maglisco stroke phases [12]. This data was useful for trainers and coaches because the movement patterns for swimmers can be obtained from the wrist acceleration data. However, no real time feedback to a swimmer was provided in this system.

Hageema et al [13-16] reported an optical feedback system and a wrist mounted accelerometer prototype. The system was bulky and difficult to deploy. This paper reports a modified system with reduced size, weight and improved intelligence.

### 3. System design

Fig. 1a shows the transmitter and Fig. 1b shows the receiver with the RGB LED on the goggles. The transmitter includes the microcontroller unit with memory. The USB connectivity is used for programming the microcontroller, charging the battery and downloading the saved data for validation purposes. The 3-axis accelerometer, power supply and battery charging circuit are included in the circuit board. The modulation chip [13-15] generates a frequency shift keyed (FSK) signal containing the stroke rate calculated from the acceleration data. This is sent to a MOSFET for on-off keying, and the green LEDs are turned on and off according to the in-coming data. The size of the transmitter is  $35 \times 35 \text{ mm}^2$ . The transmitter cost is \$19.89AU.

The receiver circuit is based on a photodiode with the transimpedance amplifier. The optical filter and the band pass electrical filter pass the desired wavelength in the green range. The demodulator uses a phase locked loop and a threshold detection circuit to make the signal appropriate for the USB. The decision algorithm embedded in the microcontroller controls one LED on the goggles turning the colours from red, green or blue. The size of the receiver circuit board is  $45 \times 30 \text{ mm}^2$ .

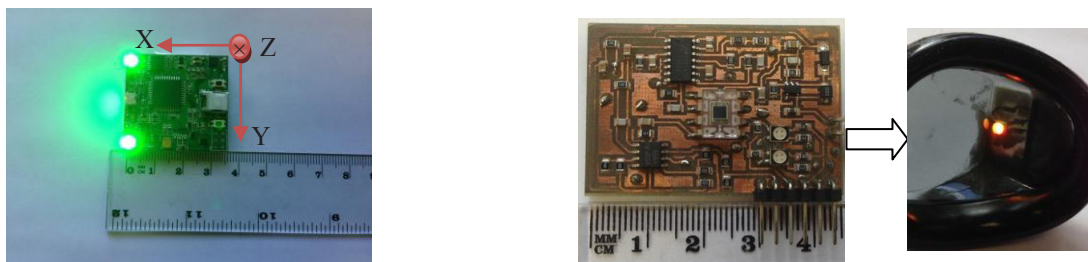


Fig. 1(a) The transmitter circuit showing three green LEDs (two vertical and one horizontal); (b) The receiver left and the RGB goggles right

#### 4. Embedded algorithms for the transmitter and the receiver

The algorithm to extract the stroke rate is based on detecting the acceleration peak caused by the impact of the arm on the water surface [1]. Fig. 2 shows the transmitter and the receiver algorithms [16]. The maximum algorithm at the transmitter is checking the acceleration y-axis raw data points to find the maximums acceleration and their times and find the time difference between two consecutive strokes. The time difference is sent to the receiver to activate the RGB LED according to a decision algorithm embedded at the receiver to turn on the red LED for the “too slow” stroke rate or the green LED for the “correct” pace or the blue LED for the “too fast” stroke rate.

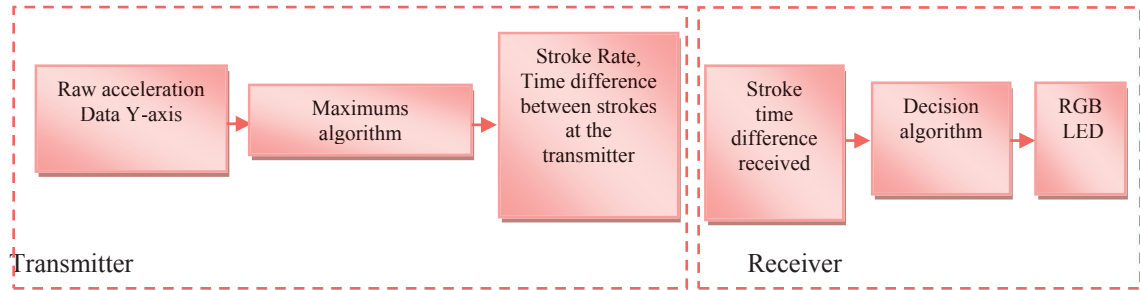


Fig. 2. The transmitter and the receiver algorithms

#### 5. Experiments

Experiments were conducted using a swimmer stroking in both air and water to validate the system. The bit error test (BER) results in air using the top and the side view LEDs is shown in Fig. 3a. An 8 bit value was sent every 50 ms for 30 s and the BER was calculated. It is clear that the top view LEDs with higher luminous intensity are better than the side view LED with 70 cm error free from the top view LEDs compared with 35 cm from the side view. Fig. 3b shows the air acceleration test for free style motion. This figure shows that the y axis acceleration which represents the direction from left hand little finger to thumb (ulnar-radial direction) [11] is best to use for stroke rate extraction.

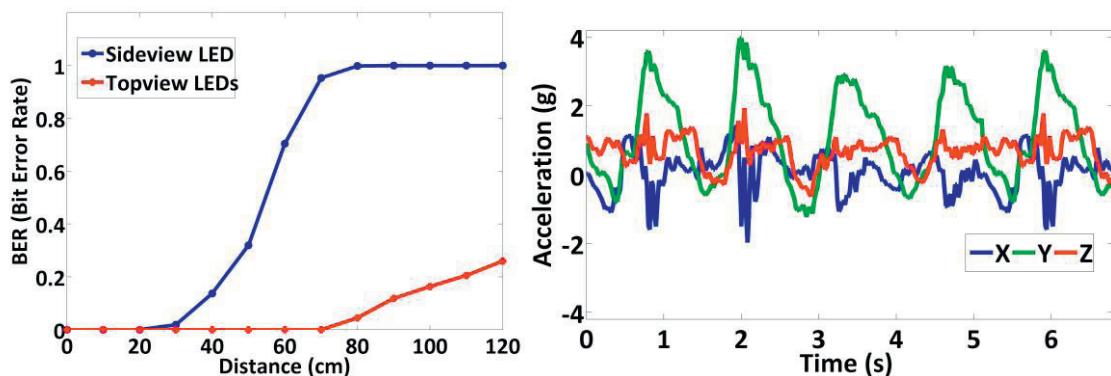


Fig. 3. (a) BER with distance for the top and side view LEDs; (b) 3 axis acceleration data for free style motion

A male recreational swimmer was asked to swim in a 50 m pool with different swimming style including: free style, backstroke, breast stroke and butterfly wearing the first version of the optical

wireless transmitter on his wrist and the optical wireless receiver on his goggles. The percentage of received data was calculated for all four swim strokes. Fig. 4 shows the system test in a backstroke swim. The results from the swim speed experiment showed that the maximum time difference between strokes for this swimmer was 2.36 s at a slow swim speed and the minimum was 1.6 s at the fast swim speed for this swimmer. The results from the swim style test experiment showed that breast stroke has the highest received data with 60.3% and 54.3%, 50.5% and 45.25% for the free style, butterfly and back stroke respectively.



Fig. 4. Testing the real time swimmers feedback system

## 6. Discussion and conclusions

A second generation swimmers feedback system was designed, implemented and tested. The air test shown that the system is error free for 70 cm with the top view LEDs and 35 cm with the side view mounted on the wrist strap. The swim test for different styles showed that breast stroke was best with 60.3% error free received data compared with other styles.

For future work, the coach-friendly graphical user interface will allow the coach to preset the swim speed to vary during the swimming session. This would allow the swimmer to train for a tactical race in the longer distance events. The ultimate goal is to provide the swimmer with swim velocity [17].

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